CLAIMS

We claim:

1   1.   A method for manufacturing an integrated circuit having a layer of material, the layer

2   described by a layout, wherein substantially all of the layer of material will be defined using

3   phase shifting, the method comprising:

4   identifying a plurality of features in the layout to be defined using phase shifting, each of

5   the plurality of features comprised of a plurality of edges;

6   placing a plurality of shifter shapes proximate to edges of the plurality of features,

7   wherein the plurality of features includes a first feature having a first edge and a

8   second edge, the first edge adjoining the second edge, and wherein the plurality of

9   shifter shapes includes a first shifter shape placed on a first edge and a second

10   shifter shape placed on a second edge, the first shifter shape and the second shifter

11   shape separated by a minimum distance;

12   assigning phase to the plurality of shifter shapes according to phase dependencies and

13   costs to create a plurality of phase shifters; and

14   refining the plurality of phase shifters.

1   2.   The method of claim 1, wherein the placing the plurality of shifter shapes further

2   comprises: defining a maximum shifter area, the maximum shifter area surrounding the plurality

3   of features in the layout, the maximum shifter area corresponding to locations on the layout

4   where the plurality of shifter shapes are to be placed.

1   3.   The method of claim 1, wherein the first shifter shape and the second shifter shape

2   separated by a minimum distance further comprises placing the first shifter shape and the second

3   shifter shape such that a cut can be admitted between the first shifter shape and the second shifter

4   shape.

1   4.   The method of claim 1, wherein the assigning further comprises using a plurality of cost

2   functions for describing the relative quality of accepting a particular phase assignment, the

3   plurality of cost functions including one or more of an inner corner cost function, an outer corner

4   cost function, a three edge cost function, a small shifter area cost function, a phase conflict cost

5   function, and a multi-layer cost function.

1   5.   The method of claim 1, wherein the refining further comprises one or more of:

2   merging adjacent phase shifters in the plurality of phase shifters that have the same

3   phase;

4   extending phase shifters in the plurality of phase shifters by squaring off corners;

5   extending phase shifters in the plurality of phase shifters by filling open spaces between

6   adjacent phase shifters with dominant or subordinate phase; and

7   adjusting shifter shapes to be design rule check compliant.

1   6.   The method of claim 1, further comprising defining a plurality of trim shapes from the

2   plurality of features and the plurality of phase shifters.

1   7.   The method of claim 6, further comprising:

2   generating a first mask data file from the plurality of phase shifters; and

3   generating a second mask data file from the plurality of trim shapes.

1   8.   The method of claim 1, wherein the placing further comprises using an initial shifter

2   shape for the plurality of shifter shapes, the initial shifter shape comprised of a trapezoid stacked

3   on top of a rectangle, wherein the rectangular portion immediately adjacent feature edges.

9.   The method of claim 1, wherein substantially all of the layer of material will be defined

5   using phase shifting further comprises one or more of the following: at least eighty percent

(80%) of the non-memory portions of the layer are defined by the plurality of phase shifters; at

least eighty percent (80%) of a part of the floorplan in the layout is defined by the plurality of

phase shift shifters; at least ninety percent (90%) of the layout is defined by the plurality of phase

shifters; all of the features in the critical path of the layout are defined by the plurality of phase

10   shifters; all features in the layout except those features that are not phase shifted due to phase

conflicts are defined by the plurality of phase shifters; everything in the layout except test

structures are defined by the plurality of phase shifters; and everything in the layout except

dummy structures are defined by the plurality of phase shifters.

1   10.   A computer data signal embodied in an electromagnetic waveform for producing a

2   computer readable definition of a photolithographic mask that define a target pattern in a layer to

3   be formed using the photolithographic mask, the computer data signal comprising:

4   a source code segment for identifying a plurality of features in the target pattern to be

5   defined using phase shifting, each of the plurality of features comprised of a

6   plurality of edges;

7   a source code segment for placing a plurality of shifter shapes in the computer readable

8   definition of the photolithographic mask, the plurality of shifter shapes placed

9   proximate to edges of the plurality of features, wherein the plurality of features

10   includes a first feature having a first edge and a second edge, the first edge

11   adjoining the second edge, and wherein the plurality of shifter shapes includes a

12   first shifter shape placed on a first edge and a second shifter shape placed on a

13   second edge, the first shifter shape and the second shifter shape separated by a

14   minimum distance;

15   a source code segment for assigning phase to the plurality of shifter shapes according to

16   phase dependencies and costs to create a plurality of phase shifters; and

17   a source code segment for refining the plurality of phase shifters.

1   11.   The computer data signal of claim 10, wherein the source code segment for assigning

2   phase further comprises a source code segment for branch-and-bound phase assignment.

1   12.   The computer data signal of claim 10, wherein the source code segment for assigning

2   phase further comprises a source code segment for graph-based phase assignment.

1   13.   The computer data signal of claim 10, further comprising a source code segment for

2   producing a computer readable definition of a second photolithographic mask, the second

3   photolithographic mask comprising a complimentary mask to be used in conjunction with the

4   photolithographic mask to define the target pattern, the second photolithographic mask defined

5   using the target pattern and the plurality of shifter shapes.

1   14.   The computer data signal of claim 13, wherein the second photolithographic comprises at

2   least one of a trim mask, a tri-tone mask, an attenuated phase shifting mask, and a binary mask.

1   15.   The computer data signal of claim 10, wherein the target pattern represented as a

2   computer data signal in a first file format and wherein the computer readable definition of the

3   photolithographic mask represented as a computer data signal in a second file format.

1   16.   The computer data signal of claim 15, wherein the first file format and the second file

2   format are the same format.

1   17.   The computer data signal of claim 15, wherein the first file format comprises a GDS-II

2   stream format and the second file format comprises a mask data file in a format suitable for use

3   in mask fabrication machines.

1   18.   A photolithographic mask for defining a target pattern in a layer to be formed using the

2   photolithographic mask, the target pattern comprised of a plurality of features, the

3   photolithographic mask comprising:

4   a dark field mask having phase shifting openings, the phase shifting openings defined by

5   a process comprising

6   placing a plurality of shifter shapes proximate to edges of the plurality of features,

7   wherein the plurality of features includes a first feature having a first edge

8   and a second edge, the first edge adjoining the second edge, and wherein

9   the plurality of shifter shapes includes a first shifter shape placed on a first

10   edge and a second shifter shape placed on a second edge, the first shifter

11   shape and the second shifter shape separated by a minimum distance;

12   assigning phase to the plurality of shifter shapes according to phase dependencies

13   and costs to create a plurality of phase shifters;

14   refining the plurality of phase shifters; and

15   producing a computer readable definition of the photolithographic mask.

1   19.   The photolithographic mask of claim 18, wherein the placing further comprises placing

2   the first shifter shape and the second shifter shape such that a cut can be admitted between the

3   first shifter shape and the second shifter shape.

1   20.   The photolithographic mask of claim 19, wherein the cut comprises an opening

2   comprised of a substantially square notch that is intersected at an offset on a forty-five degree

3   (45°) angle by a straight neck that ends in a squared off form.

1   21.   The photolithographic mask of claim 19, wherein the cut comprises a minimum mask

2   manufacturing width opening between two adjacent shifter shapes.

1   22.   The photolithographic mask of claim 18, wherein the target pattern characterized by one

2   or more of the following: at least eighty percent (80%) of the non-memory portions of the layer

3   are defined by the photolithographic mask; at least eighty percent (80%) of a part of the floorplan

4   in the layer is defined by the photolithographic mask; at least ninety percent (90%) of the layer is

5   defined by the photolithographic mask; all of the features in the critical path of the layer are

6   defined by the photolithographic mask; all features in the layer except those features that are not

7   phase shifted due to phase conflicts are defined by the photolithographic mask; everything in the

8   layer except test structures are defined by the photolithographic mask; and everything in the

9   layer except dummy structures are defined by the photolithographic mask.

1   23.   An apparatus for defining a computer readable definition of a photolithographic mask of

2   a target pattern in a layer of material of an integrated circuit, the target pattern comprised of a

3   plurality of features, the apparatus comprising:

4   means for defining a maximum shifter area around the plurality of features in the target

5   pattern;

6   means for placing shifter shapes in the computer readable definition of the

7   photolithographic mask, the shifter shapes placed within the maximum shifter

8   area such that the shifter shapes run along edges of the plurality of features and

9   such that space is left between adjacent shifter shapes to admit a cut;

10   means for assigning phase to the plurality of shifter shapes according to phase

11   dependencies and costs;

12   means for refining the shifter shapes; and

13   means for outputting the computer readable definition of the photolithographic mask

14   including the plurality of shifter shapes.

1   24.   The apparatus of claim 23, further comprising means for producing a computer readable

2   definition of a complementary photolithographic mask from the target pattern and the plurality of

3   shifter shapes.

1   25.   The apparatus of claim 23, wherein the means for assigning further comprises means for

2   computing a cost for a given phase assignment to a phase shifter in the plurality of shifter shapes,

3   the cost corresponding to the relative quality of the given phase assignment.

1   26.   An article of manufacture comprising a computer readable storage medium, having stored

2   thereon computer readable instructions for definition of a photolithographic mask that define a

3   target pattern in a layer to be formed using the mask, wherein said pattern includes a plurality of

4   features; the computer readable instructions comprising:

5   a first set of instructions for accessing the target pattern;

6   a second set of instructions for defining a maximum shifter area around the plurality of

7   features in the target pattern;

8   a third set of instructions for placing shifter shapes in the computer readable definition of

9   the photolithographic mask, the shifter shapes placed within the maximum shifter

10   area such that the shifter shapes run along edges of the plurality of features and

11   such that space is left between adjacent shifter shapes to admit a cut;

12   a fourth set of instructions for assigning phase to the plurality of shifter shapes according

13   to phase dependencies and costs;

14   a fifth set of instructions for refining the shifter shapes; and

15   a sixth set of instruction for storing the computer readable definition of the

16   photolithographic mask.

1   27.   The article of manufacture of claim 26, wherein the fourth set of instructions further

2   comprises a set of instructions for using a plurality of cost functions to describe the relative

3   quality of accepting a particular phase assignment, the plurality of cost functions including one

4   or more of an inner corner cost function, an outer corner cost function, a three edge cost function,

5   a small shifter area cost function, a phase conflict cost function, and a multi-layer cost function.

1   28.   The article of manufacture of claim 26, wherein the fourth set of instructions further

2   comprises a set of instructions for performing branch-and-bound to assign phase.

1   29.   The article of manufacture of claim 26, wherein the second set of instructions further

2   comprises a set of instructions for growing a boundary around the plurality of features except at

3   end-caps to define the maximum shifter area.

1   30.   The article of manufacture of claim 26, wherein the second set of instructions further

2   comprises a set of instructions for defining a minimum shifter area and an endcap cutting

3   protection, and where the defining the maximum shifter area accounts for the endcap cutting

4   protection.

1   31.   The article of manufacture of claim 26, wherein the second set of instructions further

2   comprises a set of instructions for clustering the plurality of features into a plurality of groups,

3   each group susceptible to independent parallel processing through the third, fourth, and fifth set

4   of instructions.

1   32.   The article of manufacture of claim 31, wherein the second set of instructions further

2   comprises a set of instructions for defining a minimum shifter area and an endcap cutting

3   protection, and where the defining the maximum shifter area protects the endcap cutting

4   protection.

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